Cryptogamie, Mycologie, 2003, 24 (2): 175-185

Lichen recolonization of *Tilia* trees in Arezzo (Tuscany, central Italy) under conditions of decreasing air pollution

Stefano LOPPI, Antonella BOSI, Chiara SIGNORINI, Vincenzo DE DOMINICIS

Dipartimento di Scienze Ambientali "G. Sarfatti", Università di Siena, Via P.A. Mattioli 4, I-53100 Siena, Italy (loppi@unisi.it)

Abstract – The results of a biomonitoring survey carried out in the town of Arezzo (central Italy) using the biodiversity of epiphytic lichens as indicator of environmental quality are reported. Lichen biodiversity counts raised progressively with distance from the old town centre, with concentric zones extending from the central parts towards the edge of town. Compared with the situation of 1994, ameliorating conditions were found, with higher biodiversity values and new colonizing species at all stations. This trend was confirmed by analytical measurements, which showed decreasing values for the most common phytotoxic gaseous pollutants (SO_2, NO_X). Increasing use of unleaded fuel and catalytic vehicles, as well as areas of the town closed to traffic and conversion to methane for domestic heating are probable reasons for this improvement.

air quality / biodiversity / biomonitoring / lichens / Italy / recolonization

INTRODUCTION

During the last years, lichen biomonitoring studies have shown a marked recolonization as a consequence of decreasing air pollution following clean air legislation. The reappearance of lichens in areas previously devoid of lichens ("lichen desert") and the improvement of the lichen biodiversity in many areas is a phenomenon which greatly expanded in the last years, also in large conurbations such as Munich (Kandler & Poelt, 1984), London (Hawksworth & McManus, 1989), Paris (Seaward & Letrouit-Galuinou, 1991) and Turin (Piervittori *et al.*, 1996).

The recolonization process has raised a great lichenological interest, but its correct evaluation has been possible only when old data or periodic observations were available and a strictly standardized sampling protocol was followed, allowing comparison of the results at different time periods. In Tuscany (central Italy), lichen biomonitoring studies greatly intensified during the last years, also with revisiting or remapping surveys after a lag-time. Retrospective studies after 15-16 years performed at two remote areas indicated that air quality at both sites remained fairly good throughout the whole period (Loppi & De Dominicis, 1996; Loppi *et al.*, 1998). Several other temporal studies were carried out in urban areas. Then town of Montecatini Terme has been mapped five times in the years 1993, 1996, 1998, 1999 and 2000 (Loppi & Corsini, 1995; Loppi *et al.*, 1997; Loppi, unpubl.), and since 1996 a great improvement in lichen abundance has been observed in connection with low levels of SO_2 and decreasing concentrations of NO_X. In the town of Pisa, at most sites where a "lichen desert" was found in 1994 (Possenti, 1994), recolonization by small thalli have been observed in 1997 (Benedettini *et al.*, 1997), clearly indicating ameliorating conditions.

The town of Arezzo has been investigated in 1994 (Loppi *et al.*, 1996) and the results suggested that a high lichen recolonization should have taken place since 1980, under conditions of falling SO_2 levels. The aim of this study was to assess the present status of the air quality in the town of Arezzo and to evaluate the process of lichen recolonization by comparing the present results with those of 1994.

MATERIALS AND METHODS

The study was carried out in the urban area of Arezzo (about 91,000 inhabitants), in central Italy (Fig. 1). Between November 1999 and February 2000, the lichen vegetation was examined in the same 15 sampling stations visited between March and October 1994 (Loppi *et al.*, 1996). Likewise in

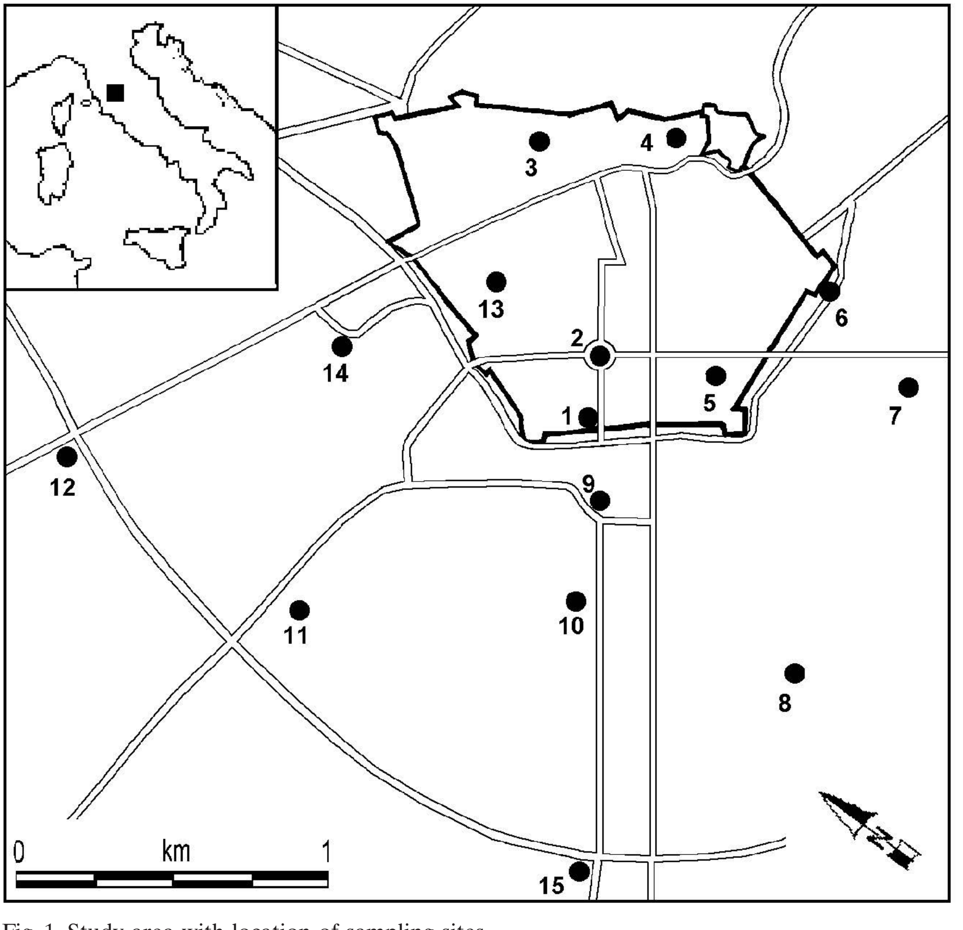

Fig. 1. Study area with location of sampling sites.

1994, in each station, 3-10 free-standing lime trees (*Tilia* sp.) having a trunk circumference not less than 70 cm, inclination not exceeding 10 degrees and not showing signs of disturbance were sampled. An attempt was made to investigate the same trees sampled in 1994, but these were not marked during the previous survey. In each station, the lichen biodiversity (LB) was measured as the sum of frequencies of epiphytic lichens in a sampling grid of 30 × 50 cm divided into 10 units of 10 × 15 cm. The bottom of this grid was placed on tree trunks at a height of 100-120 cm from the ground, in the part of the bole with the highest lichen abundance. All the lichen species found within the grid were noted together with their frequency, namely the number of grid units in which the species was present. The sum of frequencies of all the species was the LB of the tree. The LB for each station was taken as the maximum calculated, expecting to reflect the potential performance of the epiphytic lichen vegetation in that station.

A two-dimensional zone-map was drawn using the plotting program SURFER (Golden Software Inc., Colorado), which transforms discrete data into a continuous distributional model, using kriging (geostatic autocorrelation of the nearest randomly placed value to produce an estimate of minimum least squares variance) as interpolation algorithm (Olea, 1974). Species nomenclature followed the on-line checklist of Italian lichens (Nimis, 2000).

RESULTS AND DISCUSSION

Forty lichen species were found in the study area (Tab. 1); the genus with the highest number of species was *Parmelia* (9 species); the commonest species were *Physcia adscendens* (93.3% of stations), *Xanthoria parietina* (80%), *Candelaria concolor* (66.7%) and *Hyperphyscia adglutinata* (66.7%). Interestingly, *X. parietina* was absent only in those three stations showing the lowest biodiversity values (st. 1, 2, 13). It is noteworthy that the species most frequent in the study area are those most widespread also in the whole Italy. As far as growth forms are concerned, foliose species were dominant (65%), followed by crustose ones (25%); leprose lichens (2.5%) were represented only by *Lepraria* sp., while fruticose ones (7.5%) by *Evernia prunastri*, *Ramalina fastigiata* and *Usnea* sp. In general, the lichen vegetation was a mixture of *Xanthorion* and *Parmelion* synusiae.

Lichen biodiversity counts can be taken as estimates of environmental quality: high values correspond to good situations while low values indicate poor quality. Such measures are chiefly depending from the two main reactions of epiphytic lichen communities to air pollution by phytotoxic gases, especially SO_2 and NO_X: a decrease in the number of species and in their cover/frequency (Nimis, 1999). The LB values measured in the present study (Tab. 2) ranged from 23 (st. 2, one of the main squares of the town) to 104 (st. 8, a park at the edge of the town) and generally were quite high. The mean LB value for the whole study area was 63.3 ± 27.8; the coefficient of variation was rather high (43.9%), indicating fairly heterogeneous LB values within the study area. The LB values were interpreted in terms of deviations from normal conditions (Tab. 3), using a scale of environmental naturality/alteration calibrated for trees on the Tyrrhenian side of Italy (Loppi *et al.*, 2002). The isopleth map of LB values plotted on the basis of this scale is shown in Figure 2.

LB values raised progressively with distance from the old town centre, with somewhat concentric zones extending from the central parts towards the

Table 1. Lichen species found in each sampling station along with their frequency.

Sampling station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acrocordia gemmata	-	-	-	-	-	-	-	-	-	-	-	-	5	-	-
Amandinea punctata	-	-	-	5	-	-	10	7	-	-	-	-	-	-	-
Caloplaca flavorubescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Candelaria concolor	7	2	-	10	2	10	9	8	5	-	-	4	-	-	7
Candelariella reflexa	-	-	-	-	-	-	-	-	6	5	-	-	-	-	2
Candelariella vitellina	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-
Candelariella xanthostigma	-	-	-	-	7	-	-	10	-	-	5	-	-	-	-
Evernia prunastri	-	-	-	3	-	9	-	3	-	6	-	-	-	-	-
Hyperphyscia adglutinata	10	-	10	10	10	-	10	10	8	-	10	10	-	2	-
Hypogymnia physodes	-	-	-	-	-	5	-	-	7	2	-	-	-	-	-
Lecania naegelii	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Lecanora carpinea	-	-	1	-	-	-	4	5	-	4	-	1	-	10	5
Lecanora chlarotera	-	-	1	-	-	-	3	4	-	-	-	-	-	4	10
Lecanora hagenii	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
Lecanora horiza	-	-	3	-	-	-	4	1	-	-	-	-	-	-	-
Lecidella elaeochroma	-	-	10	-	-	-	9	10	-	9	5	5	-	10	10
Lepraria sp.	1	-	5	10	-	-	1	5	-	5	-	-	10	-	-
Normandina pulchella	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Parmelia acetabulum	-	-	-	-	-	-	-	2	1	4	-	-	-	-	-
Parmelia caperata	-	1	-	10	-	7	4	5	10	8	-	-	-	-	4
Parmelia elegantula	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Parmelia exasperatula	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
Parmelia quercina	-	-	-	-	-	3	-	1	1	-	-	-	-	-	-
Parmelia subaurifera	-	-	-	10	-	10	2	-	-	10	-	-	-	-	-
Parmelia subrudecta	-	4	-	10	1	4	-	1	2	-	-	1	-	-	3
Parmelia sulcata	-	-	-	10	1	10	3	6	10	10	-	-	-	-	-
Parmelia tiliacea	-	-	-	1	2	3	3	-	2	5	-	-	-	-	-
Phaeophyscia chloantha	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Phaeophyscia hirsuta	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-
Phaeophyscia orbicularis	3	-	-	5	-	1	2	-	-	-	10	10	-	3	1
Physcia adscendens	5	10	10	10	10	10	10	10	10	10	10	10	-	10	10
Physcia aipolia	-	-	-	-	-	1	1	-	-	-	-	-	-	-	-
Physcia biziana	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
Physcia stellaris	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-
Physconia distorta	-	-	-	-	-	1	5	-	-	2	-	-	-	-	-
Physconia grisea	-	-	10	7	2	3	-	-	-	-	7	2	10	-	-
Ramalina fastigiata	-	-	-	-	-	-	-	-	10	2	-	-	-	-	1
Rinodina pyrina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Usnea sp.	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Xanthoria parietina	-	-	6	2	2	4	6	5	1	1	1	10	-	10	5

edge of town. The western part had lower LB values, probably as a consequence of the higher traffic load and the higher density of industrial activities. The "lichen desert" was lacking, and stations classified as "altered" (st. 2 and 13) were at the

Table 2. Number of species and lichen biodiversity values at each sampling station in 1994 (Loppi *et al.,* 1996) and 2000 (present survey).

Sampling station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1994															
No. of species	0	6	6	9	9	16	5	20	12	7	7	7	3	7	7
Lichen Biodiversity	0	8	16	38	40	71	33	78	55	26	41	39	19	43	38
2000															
No. of species	5	6	9	14	10	15	20	19	15	16	7	9	3	8	14
Lichen Biodiversity	26	23	56	103	47	81	96	104	84	86	48	53	25	54	63

Table 3. Scale of environmental naturality/alteration for the interpretation of LB values on *Tilia* and deciduous *Quercus* trees on the Tyrrhenian side of Italy (Loppi *et al.,* 2000).

LB values	% deviation from normal conditions	Interpretation
0	100	lichen desert
1 – 25	75–99	alteration
25 – 50	50–75	semi-alteration
50 – 75	25–50	semi-naturality
> 75	0–25	naturality

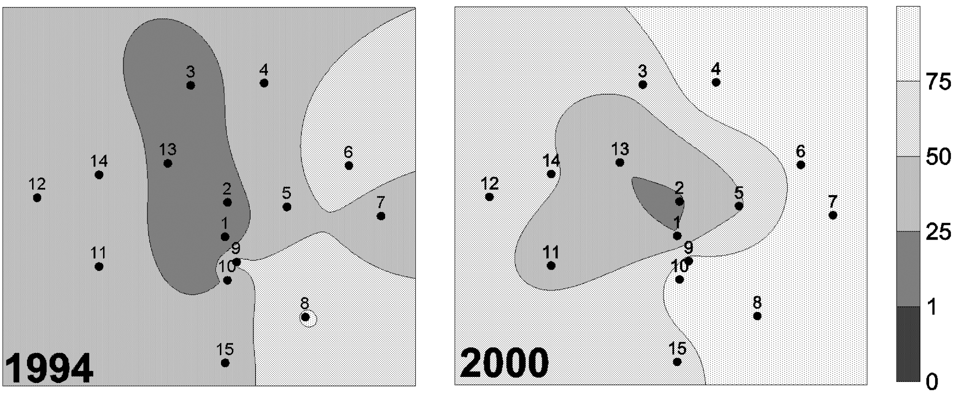

Fig. 2. Isopleth maps of lichen biodiversity values measured in 1994 and 2000 plotted on the basis of the scale of environmental naturality/alteration reported in Table 3.

upper limit for this environmental naturality/alteration class (LB values of 23 and 25 respectively); both stations were located in the inner part of the town, in areas with intense traffic (st. 2) or in the old town centre where there are very low possibilities for wind dispersal of air pollutants. All stations classified as "natural", except station 4, were found in parks outside the ancient town walls and the high

LB values found in these stations could be determined by local humidity favouring lichen vegetation in green areas. In these stations, the lichen biodiversity did not seem to be affected by air pollution and variations in lichen frequencies presumably depended on other environmental factors. Station 4 is located on the most elevated of the town and it is likely that the exposure to wintry winds from north-east induces a lower residence time of air pollutants in this station.

In Tables 4-6, for each station are reported the species found in 1994 but not in 2000 (Tab. 4), the species found both in 1994 and in 2000 (Tab. 5) and the species found only in 2000 (Tab. 6). Since a different scale was used by Loppi *et al*. (1996), to allow direct comparison, a new zone-map with the LB values measured in 1994 was drawn based on the scale of environmental naturality/alteration adopted in the present study (Fig. 2).

Table 4. Lichen species found in each sampling station in 1994 but not in 2000, along with their frequency.

Stazione	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Acrocordia gemmata	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Amandinea punctata	-	-	10	-	-	-	-	-	-	-	10	-	-	-	7
Caloplaca cerina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7
Caloplaca haematites	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-
Candelaria concolor	-	-	2	-	-	-	-	-	-	1	-	-	-	-	-
Candelariella xanthostigma	-	-	-	-	-	1	4	-	-	-	-	-	-	-	-
Hyperphyscia adglutinata	-	-	-	-	-	9	-	-	-	-	-	-	-	-	-
Lecania naegelii	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Lecanora chlarotera	-	-	-	-	-	8	-	-	-	-	-	-	-	-	-
Lecanora hagenii	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Lecanora muralis	-	-	1	-	-	-	-	1	-	-	-	-	-	-	-
Lecidella elaeochroma	-	-	-	3	-	8	-	-	-	-	-	-	-	-	-
Lepraria sp.	-	3	-	-	-	1	-	-	-	-	-	-	-	-	-
Parmelia acetabulum	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Parmelia caperata	-	-	-	-	4	-	-	-	-	-	-	-	-	-	-
Parmelia exasperata	-	-	-	-	-	-	-	-	3	-	-	-	-	-	-
Parmelia subaurifera	-	-	-	-	-	-	-	-	6	5	-	-	-	-	-
Parmelia subrudecta	-	-	-	-	-	-	-	-	-	2	-	-	-	-	-
Parmelia tiliacea	-	1	-	-	-	-	-	1	-	-	-	-	-	-	-
Physcia aipolia	-	-	-	-	-	-	-	5	-	-	-	-	-	-	-
Physcia biziana	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Physcia stellaris	-	-	-	-	4	-	-	-	4	-	-	-	-	-	-
Physcia tribacoides	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-
Physconia distorta	-	-	-	3	-	-	-	-	-	-	-	-	-	-	-
Physconia grisea	-	10	-	-	-	-	2	-	-	-	-	-	-	-	-
Physconia servitii	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-
Physconia venusta	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Rinodina pyrina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Tephromela atra	-	-	-	-	-	3	-	1	-	-	2	-	-	-	-

Table 5. Lichen species found in each sampling station both in 1994 and in 2000, along with their frequency

Stazione	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Amandinea punctata	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-
Candelaria concolor	-	-	-	10	2	-	-	8	5	-	-	-	-	-	-
1994	-	-	-	1	7	-	-	1	3	-	-	-	-	-	-
Candelariella reflexa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
1994	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Candelariella xanthostigma	-	-	-	-	7	-	-	10	-	-	5	-	-	-	-
1994	-	-	-	-	5	-	-	1	-	-	6	-	-	-	-
Hyperphyscia adglutinata	-	-	-	-	10	-	-	10	-	-	10	10	-	-	-
1994	-	-	-	-	5	-	-	4	-	-	6	4	-	-	-
Hypogymnia physodes	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Lecanora carpinea	-	-	-	-	-	-	-	5	-	-	-	1	-	10	5
1994	-	-	-	-	-	-	-	8	-	-	-	3	-	7	10
Lecanora chlarotera	-	-	1	-	-	-	-	4	-	-	-	-	-	4	-
1994	-	-	2	-	-	-	-	5	-	-	-	-	-	2	-
Lecanora hagenii	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-
Lecidella elaeochroma	-	-	-	-	-	-	-	10	-	-	-	5	-	-	10
1994	-	-	-	-	-	-	-	10	-	-	-	10	-	-	10
Lepraria sp.	-	-	-	10	-	-	-	5	-	-	-	-	10	-	-
1994	-	-	-	6	-	-	-	4	-	-	-	-	5	-	-
Parmelia acetabulum	-	-	-	-	-	-	-	2	1	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	3	1	-	-	-	-	-	-
Parmelia caperata	-	1	-	10	-	7	-	5	10	8	-	-	-	-	4
1994	-	2	-	2	-	1	-	1	8	1	-	-	-	-	-
Parmelia quercina	-	-	-	-	-	-	-	1	1	-	-	-	-	-	-
1994	-	-	-	-	-	-	-	3	2	-	-	-	-	-	-
Parmelia subaurifera	-	-	-	10	-	10	-	-	-	10	-	-	-	-	-
1994	-	-	-	8	-	5	-	-	-	9	-	-	-	-	-
Parmelia subrudecta	-	-	-	10	-	-	-	1	-	-	-	-	-	-	-
1994	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-
Parmelia sulcata	-	-	-	10	-	10	-	6	10	10	-	-	-	-	-
1994	-	-	-	1	-	5	-	6	10	2	-	-	-	-	-
Parmelia tiliacea	-	-	-	1	-	3	-	-	2	-	-	-	-	-	-
1994	-	-	-	3	-	4	-	-	2	-	-	-	-	-	-
Phaeophyscia orbicularis	-	-	-	-	-	-	-	-	-	-	10	-	-	-	-
1994	-	-	-	-	-	-	-	-	-	-	3	-	-	-	-
Physcia adscendens	-	10	-	10	10	10	10	10	10	10	10	10	-	10	10
1994	-	1	-	10	10	10	10	10	10	10	10	10	-	6	10
Physcia aipolia	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	4	-	-	-	-	-	-	-	-	-
Physconia distorta	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
1994	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Physconia grisea	-	-	-	-	-	3	-	-	-	-	-	-	10	-	-
1994	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-
Xanthoria parietina	-	-	6	-	2	4	6	5	-	-	-	10	-	10	5
1994	-	-	1	-	1	5	10	3	-	-	-	10	-	6	4

Table 6. Lichen species found in each sampling station in 1994 but not in 2000, along with their frequency.

Sampling station	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Amandinea punctata	-	-	-	5	-	-	10	-	-	-	-	-	-	-	-
Caloplaca flavorubescens	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1
Candelaria concolor	7	2	-	-	-	10	9	-	-	-	-	4	-	-	-
Candelariella reflexa	-	-	-	-	-	-	-	-		5	-	-	-	-	2
Candelariella vitellina	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-
Evernia prunastri	-	-	-	3	-	9	-	3	-	6	-	-	-	-	-
Hyperphyscia adglutinata	10	-	10	10	-	-	10	-	8	-	-	-	-	2	-
Hypogymnia physodes	-	-	-	-	-	5	-	-	-	2	-	-	-	-	-
Lecania naegelii	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Lecanora carpinea	-	-	1	-	-	-	4	-	-	-	-	-	-	-	-
Lecanora chlarotera	-	-	-	-	-	-	3	-	-	-	-	-	-	-	10
Lecanora horiza	-	-	3	-	-	-	4	1	-	-	-	-	-	-	-
Lecidella elaeochroma	-	-	10	-	-	-	9	-	-	-	5	-	-	10	-
Lepraria sp.	1	-	5	-	-	-	1	-	-	-	-	-	-	-	-
Normandina pulchella	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-
Parmelia acetabulum	-	-	-	-	-	-	-	-	-	4	-	-	-	-	-
Parmelia caperata	-	-	-	10	-	-	4	-	-	-	-	-	-	-	-
Parmelia elegantula	-	-	-	-	-	-	-	-	10	-	-	-	-	-	-
Parmelia exasperatula	-	-	-	-	-	-	-	10	-	-	-	-	-	-	-
Parmelia quercina	-	-	-	-	-	3	-	-	-	-	-	-	-	-	-
Parmelia subaurifera	-	-	-		-		2	-	-		-	-	-	-	-
Parmelia subrudecta	-	4	-	-	1	4	-	-	2	-	-	1	-	-	3
Parmelia sulcata	-	-	-	-	1	-	3	-	-	-	-	-	-	-	-
Parmelia tiliacea	-	-	-	-	2	-	3	-	-	5	-	-	-	-	-
Phaeophyscia chloantha	-	4	-	-	-	-	-	-	-	-	-	-	-	-	-
Phaeophyscia hirsuta	-	-	-	-	10	-	-	-	-	-	-	-	-	-	-
Phaeophyscia orbicularis	3	-	-	5	-	1	2	-	-	-	-	10	-	3	1
Physcia adscendens	5	-	10	-	-	-	-	-	-	-	-	-	-	-	-
Physcia aipolia	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
Physcia biziana	-	-	-	-	-	-	-	-	-	-	-	-	-	5	2
Physcia stellaris	-	-	-	-	-	-	-	1	-	3	-	-	-	-	-
Physconia distorta	-	-	-	-	-	-	5	-	-	2	-	-	-	-	-
Physconia grisea	-	-	10	7	2	-	-	-	-	-	7	2	-	-	-
Ramalina fastigiata	-	-	-	-	-	-	-	-	10	2	-	-	-	-	1
Rinodina pyrina	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2
Xanthoria parietina	-	-	-	2	-	-	-	-	1	1	1	-	-	-	-

Comparing the results of 1994 with the present data, a general amelioration emerged, as evidenced by the increase in LB values at all sampling stations (Tabs. 2 and 7, Fig. 2). In 1994, one station (st. 1, close to the railway station) was totally devoid of lichens ("lichen desert"), while in the present survey, colonization by 5 lichen species occurred (*Candelaria concolor, Hyperphyscia adglutinata,*

Table 7. Number of station (% in parentheses) for each environmental naturality/alteration class in 1994 and 2000.

	1994	2000
lichen desert	1 (6.7 %)	0 (0%)
alteration	3 (20%)	2 (13.3%)
semi-alteration	8 (53.3%)	3 (20%)
semi-naturality	2 (13.3%)	4 (26.6%)
naturality	1 (6.7%)	6 (40%)

Lepraria sp., Phaeophyscia orbicularis, Physcia adscendens). All of the above species reproduce mainly asexually, by soredia or soredia-like structures, and this may explain their high colonizing capacity (Bailey, 1976). This is further confirmed by the fact that *H. adglutinata*, *C. concolor* and *P. orbicularis* were new to most stations (Tab. 6). Another factor promoting these *Xanthorion* species could be dust impregnation of the tree bark caused by vehicular traffic as a consequence of dust and spray lifted by cars (Gilbert, 1976; Loppi, 1996; Loppi & Pirintsos, 2000; Del Guasta, 2000). *Parmelia subrudecta* showed a high colonizing power (Tab. 6) and this fact, coupled with the increase in frequency values of *P. caperata* and *P. sulcata* (Tab. 5) with respect to the 1994 survey, suggests that recolonization has occurred also by *Parmelion* species, which are sensitive to air pollution (Barkman, 1958).

Species found in 1994 and not met again in the present survey were *Caloplaca cerina*, *Caloplaca haematites*, *Lecanora muralis, Parmelia exasperata*, *Physcia tribacoides, Physconia servitii*, *Physconia venusta* and *Tephromela atra*. All of the above species, in 1994 were present only sporadically and may have been overlooked in 2000, possibly because different trees were sampled or a different position on the bole for the sampling grid was selected. Species found in 2000 but not in 1994 were *Caloplaca flavorubescens, Candelariella vitellina, Evernia prunastri, Lecania naegelii, Lecanora horiza, Normandina pulchella, Parmelia exasperatula, Phaeophyscia chloantha, Phaeophyscia hirsuta* and *Ramalina fastigiata*. Also most of these species were found only sporadically. It is noteworthy the finding of two fruticose lichens (*E. prunastri* and *R. fastigiata*) since species with this growth form, which are regarded as the most sensitive to air pollution (Gilbert, 1973), were not found in 1994.

The general increase in lichen biodiversity found in the present survey compared to the investigation of 1994 (Loppi *et al*., 1996) is probably determined by an improvement in air quality over time. The analytical measurements of air pollutants available for the study area (Provincia di Arezzo, 1999) confirm this hypothesis, since a decreasing trend was recorded for pollutants such as NO_x and CO. As an example, concentrations of NO_2 decreased from 165 µg/m^3 in 1991 (range 114-253) to 112 µg/m^3 in 1995 (range 90-144), down to 96 µg/m^3 in 1998 (range 80-106). SO_2 concentrations decreased to such en extent (from about 150-200 µg/m^3 in 1980, to 15-20 µg/m^3 in 1994 and 4-8 µg/m^3 in 1998) that this pollutant in no longer measured. This improvement is chiefly attributable to the increasing use of unleaded fuel and catalytic vehicles, as well as to areas of the town closed to traffic and conversion to methane for domestic heating (Provincia di Arezzo, 1999).

CONCLUSIONS

The process of lichen recolonization in the town of Arezzo already shown in 1994 (Loppi *et al*., 1996) has been fully confirmed by the results of the present survey, with higher biodiversity values and new colonizing species at all stations. The worst situation ("environmental alteration") was found in the old town centre, which however was close to the upper limit for the next class of "semi-alteration", clearly indicating ameliorating conditions. This trend is also confirmed by analytical measurements, which showed decreasing values for the most common phytotoxic gaseous pollutants.

Nowadays there is a great concern about environmental and human health and lichen biomonitoring surveys repeated over time are a valuable and effective tool to show air quality changes happened over time, and survey of the epiphytic lichen flora of a given area could be planned for periodical testing. However, although a high negative correlation was found in north-eastern Italy between lichen biodiversity and lung cancer as a result of air pollution (Cislaghi & Nimis, 1997), it should be stressed out that if the disappearance of lichens is a clear indication of risk also for human health, the abundance of these organisms does not allow to exclude the presence of contaminants that could be toxic to man but not to lichens.

REFERENCES

BAILEY R.H., 1976 – Ecological aspects of dispersal and establishment in lichens. pp. 215-247. *In* Brown D.H., Hawksworth D.L. & Bailey R.H. (eds.): *Lichenology: Progress and Problems*, Academic Press. London.

BARKMAN J.J., 1958 – *Phytosociology and ecology of cryptogamic epiphytes*. Van Gorcum, Assen.

BENEDETTINI G., FERRI G., TONCELLI M.L. & POSSENTI L., 1997 – *Monitoraggio della qualità dell'aria della città di Pisa tramite licheni epifiti*. ARPAT, Dipartimento Provinciale di Pisa.

CISLAGHI C. & NIMIS P.L., 1997 – Lichens, air pollution and lung cancer. *Nature* 387: 463-464.

DEL GUASTA M., 2000 – Angular distribution of epiphytic lichens on *Tilia* trees as a result of car traffic. *Allionia* 37: 233-240.

GILBERT O.L., 1973 – Lichens and air pollution. pp. 443-472. *In* Ahmadjian V. & Hale M. (eds.): *The lichens*, Academic Press, London.

GILBERT O.L., 1976 – An alkaline dust effect on epiphytic lichens. *Lichenologist* 8: 173-178.

HAWKSWORTH D.L. & MCMANUS P.M., 1989 - Lichen recolonization in London under conditions of rapidly falling sulphur dioxide levels, and the concept of zone skipping. *Botanical Journal of the Linnean Society* 100: 99-109.

KANDLER O. & POELT J., 1984 – Wiederbesiedlung der Innestadt von München durch Flechten. *Naturwissenschaftliche Rundschau* 37: 90-95.

LOPPI S., 1996 – Effects of road dust contamination on epiphytic lichen communities (central Italy). *Micologia e Vegetazione Mediterranea* 11: 155–160.

LOPPI S. & Corsini A., 1995 – Lichens as bioindicators of air quality in Montecatini Terme (central northern Italy). *Ecologia Mediterranea* 21: 87-92.

LOPPI S. & De Dominicis V., 1996 – Lichens as long-term biomonitors of air quality in central Italy. *Acta Botanica Neerlandica* 45: 563–570.

LOPPI S. & PIRINTSOS S.A., 2000 – Effect of dust on epiphytic lichen vegetation in the Mediterranean area (Italy and Greece). *Israel Journal of Plants Science* 48: 91-95.

LOPPI S., FRANCALANCI C., PACINI P., MARCHI G. & CAPORALI B., 1996 – Lichens as bioindicators of air quality in Arezzo (central Italy). *Ecologia Mediterranea* 22: 11-16.

LOPPI S., GIOVANNELLI L., PIRINTSOS S.A., PUTORTÌ E. & CORSINI A., 1997 – Lichens as bioindicators of recent changes in air quality (Montecatini Terme, Italy). *Ecologia Mediterranea* 23: 53-56.

LOPPI S., PUTORTÌ E., SIGNORINI C., FOMMEI S., PIRINTSOS S.A. & DE DOMINICIS V., 1998 – A retrospective study using epiphytic lichens as biomonitors of air quality: 1980 and 1996 (Tuscany, central Italy). *Acta Oecologia* 19: 405-408.

LOPPI S., GIORDANI P., BRUNIALTI G., ISOCRONO D. & PIERVITTORI R., 2002 – A new scale for the interpretation of lichen biodiversity values in the Tyrrhenian side of Italy. *Bibliotheca Lichenologica* 82: 237-243.

NIMIS P.L., 1999 – Linee-guida per la bioindicazione degli effetti dell'inquinamento tramite la biodiversità dei licheni epifiti. pp. 267-277. *In* Piccini C. & Salvati S. (eds.) : Atti del Workshop *Biomonitoraggio della qualità dell'aria sul territorio nazionale*, Roma, 26-27 Novembre 1998, ANPA, Roma.

NIMIS P.L., 2000 – *Checklist of Italian lichens 2.0*. University of Trieste, Department of Biology, IN2.0/2 (http://dbiodbs.univ.trieste.it/web/lich/askit1).

OLEA R.A., 1974 – Optimal contouring mapping using universal kriging. *Journal of Geophysical Research* 79: 695-702.

PIERVITTORI R., MEREGALLI M., MAFFEI S. & MONTERSINO M., 1996 – Ricolonizzazione lichenica nella città di Torino. *Allionia* 34: 63-65.

POSSENTI L., 1994 – *Monitoraggio della qualità dell'aria della città di Pisa mediante l'utilizzo di licheni epifiti come bioindicatori*. Dissertation, University of Pisa.

PRIVINCIA DI AREZZO, 1999 – *Rapporto sullo stato dell'ambiente della Provincia di Arezzo*. Assessorato all'Ambiente, Arezzo.

SEAWARD M.R.D. & LETROUIT-GALINOU M.A., 1991 – Lichen recolonization of trees in the Jardin du Luxembourg, Paris. *Lichenologist* 23: 181-186.